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ABSTRACT

In the Cheche Konnen project, secondary school language minority students plan and carry out investigations into phenomena in the natural world as scientists would ("cheche konnen" is Haitian Creole for "search for knowledge"). Students pose questions, plan and implement research to explore them, build and revise theories, collect, analyze, and interpret data, and draw conclusions and make decisions based on their research. A study examined how a group of language-minority students in a multilingual high school basic skills class began to acquire scientific ways of thinking, talking, and writing. The study was based on a student project on the bacterial content of the town's drinking water and the students' analysis of the temperature profile of a nearby pond. After a detailed description of the project it is concluded that the examples of student talk and writing gleaned from the project demonstrate the complexities in scientific sense-making and the necessary connection between sense-making and the community of practice in which it takes place. The dilemmas and issues students met grew directly from their own scientific activity, which encompassed many aspects of authentic scientific inquiry. Students became knowledge producers and active sense-makers, not simply assimilators of knowledge presented by others. (MSE)

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Making Sense of Science in Language Minority Classrooms

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Making Sense of Science in Language Minority Classrooms

This paper analyzes how a group of language minority students, many of whom had never studied science before and some of whom had very little schooling of any kind, began to acquire scientific ways of thinking, talking and writing. The context of their learning was an approach to science, Cheche Konnen,[1] that emphasizes collaborative inquiry as the basis of authentic scientific activity (Warren, Rosebery & Conant, 1989). The fundamental idea behind the approach is to involve students in "doing science" in the way that practicing scientists do. Students pose their own questions, plan and implement research to explore their questions, analyze and interpret the data they collect, and draw conclusions and make decisions based on their research.

The Cheche Konnen approach contrasts sharply with traditional classroom practice in science. As recent NAEP data show, school science often is an amalgam of lecture, demonstration, memorization and assessment (Mullis & Jenkins, 1988). Students do not typically engage in any direct or purposeful way the phenomena they are expected to understand. They may master some of the so-called "facts" of science but they learn very little about the nature of the scientific enterprise as it is practiced by professional scientists.

For language minority students, conventional school science is even more problematic. Science instruction, when it is given at all, typically takes the most limited, traditional forms. Often it is subordinated to the pressing and legitimate need to develop the students' English language abilities; students memorize the definition of the word "hypothesis" but never experience what it means to formulate or evaluate one. As a result very little science is actually learned. Perhaps more importantly, this kind of learning may inculcate negative attitudes and conceptions about science, especially in language minority students, many of whom come to school without a strong sense of what science is all about.

Scientific Sense-Making: The Art of Storytelling

Underlying school science practices, whether in mainstream or bilingual programs, is a view of science -- and with it, scientific literacy -- that is at odds

[1] Cheche Konnen means "search for knowledge" in Haitian Creole.

with the actual practice of science in the scientific community.[2] The following quote, from Sir Peter Medawar, the eminent thinker and scientist, helps elucidate these differences by describing a scientist's view of scientific activity:

> Like other exploratory processes, (the scientific method) can be resolved into a dialogue between fact and fancy, the actual and the possible; between what could be true and what is in fact the case. The purpose of scientific enquiry is not to compile an inventory of factual information, nor to build up a totalitarian world picture of Natural Laws in which every event that is not compulsory is forbidden. We should think of it rather as a logically articulated structure of justifiable beliefs about a Possible World - a story which we invent and criticise and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life. (Medawar, 1987, p. 111)

In this quotation, Medawar directly challenges some of the typical school beliefs about what it means to be scientifically literate. First, he challenges the belief that science, at bottom, is the accumulation of knowledge or facts about the natural world. Secondly, he challenges the belief that scientists work according to a rigorously defined, logical method, known popularly as The Scientific Method. And thirdly, he challenges the belief that scientific discourse is represented uniquely, or even accurately, by forms of writing and talk that are thoroughly objective and impersonal.

Central to Medawar's vision is an idea of scientific activity as involving dialogue and storytelling. Both strike a discordant note with conventional classroom practices. For example, with regard to the methods of science, we tend to confuse the final product of scientific activity, the journal paper with its clearly delineated steps and carefully argued logic, with the process that produced it. One result is that we teach *the* method of science as if it represented the way in which scientists actually go about their work. The result is a distorted view of the role of both reason and imagination in science (Kuhn, 1977; Medawar, 1987). Medawar's insistence on the dialogic quality of scientific activity, in contrast, places fact and fancy, induction and imagination on more equal footing.

Gould (1981, 1989) extends Medawar's view by making the social and cultural origins of imagination explicit:

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[2] Although it needs to be said that not all scientists are necessarily in agreement about what it is they do when they "do science."

> Science, since people must do it, is a socially embedded activity. It progresses by hunch, vision, and intuition. Much of its change through time does not record a closer approach to absolute truth, but the alteration of cultural contexts that influence it so strongly. Facts are not pure and unsullied bits of information; culture also influences what we see and how we see it. Theories, moreover, are not inexorable inductions from facts. The most creative theories are often imaginative visions imposed upon facts; the source of imagination is also strongly cultural. (Gould, 1981, pp. 21-22)

On this view, scientific literacy -- as an outgrowth of authentic scientific activity -- is more than the product of a dialectic between "fact and fancy." It is more broadly conceptualized as a socially and culturally produced way of thinking and knowing, with its own ways of talking, interacting and valuing. To become scientifically literate, therefore, students must be enculturated into the ways of making sense that characterize scientific communities.

But what is the character of scientific sense-making? Medawar suggests provocatively that scientific sense-making is akin to storytelling. But what does he mean by this? Most of our cultural assumptions about the nature of scientific knowledge, at least those that are conveyed through classroom instruction -- for example, that scientific knowledge is associated with certainty and is absolute -- do not fit with any idea of storytelling. What kind of storytelling, then, does Medawar have in mind?

What Medawar has in mind when he equates scientific inquiry with storytelling is an activity that "begins with an explanatory conjecture which at once becomes the subject of energetic critical analysis" (1987, p. 134-35). Storytelling is this activity of building explanatory structures or theories through hypothesizing and experimentation. It proceeds by hunch and intuition, invention and criticism; it is a process that is "outside logic" (Medawar, 1987, p. 129). An hypothesis functions as the germ of a story, an "imaginative preconception," whose deductive consequences are tested through experimentation and whose explanatory power is enhanced if it proves to have predictive power as well:

> A 'story' is more than a hypothesis: it is a theory, a hypothesis together with what follows from it and what goes with it, and it has the clear connotation of completeness within its own limits. I notice that laboratory jargon follows this usage, e.g. 'Let's get So-and-so to tell his story about' something or other, an invitation which So-and-so may decline on the grounds that his work 'doesn't make a story yet' or accept because he 'thinks he's got a story'.

The discourse of storytelling in science is, therefore, a discourse of theorizing that grows out of an energetic, critical process involving at a minimum conjecture, evidence, experimentation, and explanation.[3]

More broadly, Medawar's use of the term "story" to describe the purpose of scientific inquiry also suggests the human, meaning-making character of science. The scientific enterprise is as much mediated by human actions and intentions (i.e., what scientists do, how and why they do it) as by language and culture (i.e., how scientists talk or otherwise express their understanding, and the cultural and ideological frameworks -- or points of view -- within which the "facts" of science are interpreted).

This culturally situated notion of sense making is one that Gould makes more forcefully than Medawar. In "Wonderful Life: The Burgess Shale and the Nature of History" (1989), he analyzes a powerful example of storytelling in paleontology. He shows how scientific decisions in the later to be revised interpretation of the Burgess Shale fossils were conditioned by the assumptions and beliefs of the discipline and culture dominant at the time, namely, the view of evolution as progress. Storytelling is in this sense an inextricable aspect of the scientist's work. It is culturally situated; the community to which one belongs shapes one's point of view, the sense one makes of what one sees (Geertz, 1973, 1983; Lave, in preparation; Schoenfeld, in press).

Learning The Art of Scientific Storytelling

The insistence on storytelling as key to scientific sense-making differs from the notion of meaning that typifies school science and even the larger culture's understanding of science.[4] In schools, students' experience of science is very far from the idea of sense-making we have been developing. In school science, for example, there exists a body of knowledge, apparently

[3] Stewart & Hafner (1989) in a recent paper argue that even this account of the intellectual activity of scientists falls short in that it emphasizes the testing of theories (which they see as already developed ideas or "problem solutions") to the neglect of "the context of discovery" in which new ideas are developed. Still, we would argue at least for present purposes that Medawar's account represents a radical view of scientific activity compared to that which dominates conventional school practice.

[4] The public discourse of science itself may be in part responsible for the way the public perceives the scientific enterprise. As Medawar (1987) argues, scientific papers and other public reports actively misrepresent as inductive the reasoning that went into the work they describe.

beyond the individual's control, that is to be learned and that is conveyed through a largely objective discourse of explanation and fact (Lemke, 1982). Meanings are given, they are explained, and occasionally they are absorbed. They are not constructed through active theorizing (i.e., storytelling), experimentation and observation as they are in authentic scientific practice. One consequence is that the knowledge that results from conventional school science often is inert, bound to the contexts in which it was learned, precisely because it is knowledge whose sense is *given* to the learner rather than *made* by the learner (Collins, Brown & Newman, 1989; Duckworth, 1986). Another is that students come away from such schooling thinking of science as an inventory of already established fact rather than as a dynamic process of knowing and sense-making.

For students to become literate in the ways of making sense that are characteristically scientific, then, the contexts ("communities of practice") in which they learn science must reflect and support those sense-making practices (cf. Lave, in preparation; Schoenfeld, in press). But learning the practices and discourse(s) of science is a difficult and complicated process. It requires the student not simply to acquire scientific ways of doing, reasoning and talking but to find ways of making them one's own so they can serve one's own purposes (Bakhtin, 1981; Cazden, 1989).

In a recent study of fourth-graders' ways of talking science, Michaels and Bruce (1989) show how divergent students' discourse is in science. After a unit of study on the seasons, they interviewed students about their understanding of seasonal change. One student, in explaining his understanding of the seasons, "sounded scientific" because he explicitly marked causal explanations with connectives such as "because" and used model-based explanations; another "sounded unscientific" because he responded to why questions with evidence from personal experience; yet another student showed evidence of moving between discourse worlds, that of the textbook, naive observer, and formal theory building. Interestingly, not one of the students articulated the correct theory of seasonal change, despite their different ways of talking science.

One issue the Michaels & Bruce (1989) study points up is that enculturation into the practices and discourse of science likely will prove more or less difficult depending on the various other discourses in which the students participate. For discourses, by their very nature, are in conflict with one another in their underlying assumptions and values, their ways of

making sense, their viewpoints, the objects and concepts with which they are concerned (Gee, 1989). As the Michaels & Bruce (1989) study demonstrates, students do not all master the same discourses at the same time; indeed, different students control different discourses to varying degrees and struggle with others. To appropriate a particular discourse entails a long and intimate apprenticeship in a community of practice which reflects and supports scientific sense-making. As Bakhtin (1981) has argued,

> (The word in language) becomes "one's own" only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. Prior to this moment of appropriation, the word...exists in other people's mouths, in other people's contexts, serving other people's intentions: it is from there that one must take the word, and make it one's own. And not all words for just anyone submit equally easily to this appropriation, to this seizure and transformation into private property: many words stubbornly resist, others remain alien, sound foreign in the mouth of the one who appropriated them and who now speaks them; they cannot be assimilated into his context and fall out of it; it is as if they put themselves in quotation marks against the will of the speaker. Language is not a neutral medium that passes freely and easily into the private property of the speaker's intentions; it is populated -- overpopulated -- with the intentions of others. Expropriating it, forcing it to submit to one's own intentions and accents, is a difficult and complicated process. (pp. 293-294)

For language minority students, this apprenticeship is even more arduous; the distance they must travel between discourse worlds is far greater than f or mainstream students, owing to both cultural and linguistic discontinuities. School itself, in many cases, is an alien culture.

But how is enculturation into the practices and discourse of the scientific community to be accomplished? In this paper we explore some of the ways in which language minority students struggle to take control of the practices and discourse of science in the context of carrying out a scientific investigation. We then examine the role that investigation-based science plays in supporting their emerging scientific literacy.

Investigation-Based Science: The Cheche Konnen Approach

The Cheche Konnen model attempts to bridge the gap between learning science and doing science by placing investigations at the center of science education. The heart of the approach is for students to formulate questions

about phenomena for which they have some prior belief (e.g., Is our school's water safe to drink? Is the air temperature hottest at noon? Why do we have seasons?), build and criticize theories, collect and analyze data, evaluate hypotheses through experimentation, observation, measurement and simulation, and interpret and communicate their findings.

More than simply involving students in scientific inquiry, it is essential that classrooms evolve into communities in which scientific sense-making is actively practiced. Toward this end, investigations are also collaborative, just as most authentic scientific activity is. The emphasis on collaborative inquiry reflects our belief, building on Vygotsky (1978), that robust knowledge and understandings are socially constructed through talk, activity and interaction around meaningful problems and tools. Collaborative inquiry provides direct cognitive and social support for the efforts of a group's individual members. Students share the responsibility for thinking and doing, distributing their intellectual activity so that the burden of managing the whole process does not fall to any one individual. The distribution and sharing of intellectual responsibility is particularly effective for language minority students, for whom the language demands of tasks are often overwhelming and can often mask their abilities and understanding. In addition, collaborative inquiry creates powerful contexts for constructing scientific meanings. In challenging one another's thoughts and beliefs, students must be explicit about their meanings; they must negotiate conflicts in belief or evidence; and they must share and synthesize their knowledge in order to achieve a common goal, if not a common understanding (Barnes & Todd, 1977; Brown & Palincsar, in press; Hatano, 1981; Inagaki & Hatano, 1983).

Finally, investigations are interdisciplinary; science, mathematics and language (talk, reading, and writing) are intimately linked. Mathematics and language are recognized as essential tools of scientific inquiry, which stands in sharp contrast to traditional schooling in which science is separated from math and the role of language in each is hardly acknowledged. The importance of an interdisciplinary approach cannot be overstated with regard to language minority students. It involves them directly in the kinds of purposeful, communicative interactions that promote genuine language use, which arguably are the most productive contexts for language acquisition, such as talking in the context of doing science and trying to solve a meaningful problem. It also creates opportunities for students to use the languages of science and mathematics in ways that schools and the society at

large require: not just to read textbooks, but to write reports, argue a theory, develop evidence, and collaboratively solve problems.

Scientific Sense-Making in Language Minority Classrooms

In this paper we examine several examples of student's scientific sense-making in a multilingual Basic Skills class in an urban high school. The Basic Skills class is for the academically weakest language minority students. those at greatest risk for dropping out or for school failure. Some of the students in this program cannot read or write in their native languages, most have only the most rudimentary mathematics skills and have had no previous exposure to science. During the 1988-89 school year there were 22 students from a variety of linguistic and cultural backgrounds in the class. Six language groups were represented: Haitian Creole, Spanish, Portuguese, Amharic, Tigrinye, and Cape Verde Creole. Two teachers, neither of whom had previously taught science, team taught science and mathematics.

Teachers and researchers collaborated to implement the Cheche Konnen model throughout the entire school year (see Warren et al., 1989 for details). The final investigation was a study of aquatic ecosystems in which the class studied a small pond called Black's Nook Pond that borders the city's reservoir. On an earlier trip to the pond, the students had been struck by the pond's condition and its proximity to the city's drinking water supply. An empty oil barrel sat in the shallows along with a shopping cart, bottles and broken glass littered the shore; the water was murky and slick with oil. The students wondered how the pond came to be a dumping ground and if it posed any hazard to the water supply.

In the context of their field study, the students analyzed the chemical, biological, and physical characteristics of the pond and their interrelationships. The examples discussed in this paper are drawn from a related study of the bacterial content of the town's drinking water and the students' analysis of the pond's temperature profile.

Bacteria Study

As part of the larger Black's Nook Pond study, students compared the bacteria level of the pond water to the bacteria level of tap water. They were interested in two things. First, how much bacteria was in the pond? Second,

how much bacteria was in their drinking water? To investigate these questions, they learned to perform fecal coliform cultures using Millipore samplers, which are commercially available culture kits. To produce a culture, students filled a Millipore sampler (a small plastic container with a grid marked nutrient pad) with water, incubated it under a light for twenty-four hours, and then inspected the grid for bacterial colonies which appear as spots. A pamphlet accompanying the samplers allows the user to assign a water quality grade to a sample based on the number of bacterial colonies that grow.

For a variety of reasons (as often happens in scientific practice), most of the cultures did not take. A few did grow, however, and a Haitian student, Rosealta, used these as the basis for investigating the bacterial level of the city's tap water. To begin her study, Rosealta meticulously reproduced the results of one culture in her science notebook. To do this, she drew a Millipore sampler and replicated the position and size of each of the 57 bacteria colonies that had grown (see Figure 1). In the end, her drawing was an accurate rendering of the sampler and the results.

---- Insert Figure 1 about here -----

Rosealta's findings corroborated an estimate of 60 given earlier by another student who had examined the sampler with a hand lens. While she was pleased that her results agreed with the earlier estimate, Rosealta's contentment was quickly overshadowed by her realization of their significance. According to the standards stated in the Millipore pamphlet, the city's tap water was fit only for swimming, not for drinking. After much informal discussion about her findings, Rosealta documented her analysis in English under her diagram (see Figure 1).

Rosealta's analysis combines both narrative and interpretive or explanatory elements, in addition to using multiple representations for her data (e.g. graphical, numerical and verbal representations). She opens her report in the first person, recounting her procedure (counting colonies) and reporting her findings (57). She then switches to a more authoritative voice, through which she interprets the data based on standards stated in the Millipore instruction booklet. In a direct, declarative voice, she writes in the second sentence, "That's mine (That means) you can't not drink but you can swim on that water." In this way Rosealta informs her readers of the significance of her findings. As proof of her conclusion, she documents

allowable bacteria standards: "Grade B for that water because whole body contact no more than 200/100 ml." (That is, this water is Grade B because it falls between 1 - 200 colonies per 100 ml of water and Grade B water is suitable for whole body contact not drinking.)

In this one, concise report, Rosealta has coordinated several voices to construct an account and an interpretation of her findings, her struggle with correct English usage notwithstanding. What counts here is the way in which she has taken control of the bacteria study, shaped it to her own purposes and taken a point of view, and then interpreted her activity and its significance for a larger community. The levels of description and explanation, the recourse to standards and multiple representations reflect her own efforts at sense-making. As will soon become clear, the impact of Rosealta's intellectual activity is measurable as other students are drawn into this incipient sense-making culture.

Around the time of the bacteria study, the Basic Skills class was preparing for a field trip to the city's reservoir and water treatment facility. Most of the students generated questions about the reservoir based on readings from a water department pamphlet (e.g., What is clorination (sic)?). However, Rosealta initiated a second Haitian student, Martine, into her discovery of the high bacterial count of the city's tap water, and the two girls collaboratively developed a list of questions for the city's water chemist (see Table 1).

-- Insert Table 1 about here --

At several levels, the girls had to organize their discourse to accomplish a specific purpose. They had to formulate their intentions explicitly and then express them in English. Projecting ahead to the actual encounter with the chemist, they decided to write their questions down so they could read them directly to him at the water treatment plant. To accomplish their discourse intentions, the girls mobilized considerable strategic resources, in turn, actively choosing their orientation among different discourses: in this case, represented by different audiences such as the teacher, each other, their peers, and the chemist. This active choosing is apparent in their use of the first person pronoun in some of their questions; they composed these questions in their own voice, that of the interrogator. Their strategy is not altogether worked out however, as evidenced by their use of the adversarial, third person "they." Rosealta and Martine seem caught between two discourse

worlds, that of the school where "they" is appropriate and that of the real world where "you" would be the more appropriate term of address.

In this activity, we see the students beginning to effectively appropriate language to their own intention. One question, first articulated by Martine in Creole, addressed the important contradiction contained in Rosealta's results: How come they clean the water but it still has bacteria in it? Martine's attitude towards this contradiction was a mixture of indignation and excitement. She marvelled in class that her town's water, which was supposed to be clean, could have bacteria in it. On the field trip, she looked forward to the opportunity to confront the authorities at the water treatment plant with her evidence that things were not as they should be. She felt empowered by her knowledge, and in the context of traditional Haitian attitudes towards authority, her zeal to question the water treatment officials verged on the revolutionary. Unfortunately, the eagerly anticipated question-and-answer period was cancelled for lack of time. Here the teachers' intentions and those of Rosealta and Martine came into direct conflict. So bitter was Martine's disappointment that in an end of the year interview, she referred to the facility as "the place we were going to ask the people questions and we didn't get to."

Ironically, Martine's very frustration reveals the power of her experience; her frustration underscores how important the opportunity to ask her question had been to her. Like Rosealta, she had appropriated the results of the bacteria study. It did not matter that Rosealta had done the analysis. Nor did it matter that the water had originally belonged to another student. Martine's ownership, like Rosealta's, resulted from her having thought seriously about the data and having prepared to confront the authorities with them. She had connected the results directly to her own experiences in the real world. That Martine was still thinking about her missed opportunity at the end of the year, weeks after the Black's Nook Pond investigation, suggests poignantly that she internalized what she had learned, about water quality and experimental analysis on the one hand and the inherent conflict between scientific practice and school practice on the other.

Temperature Study

Several students worked on developing a temperature profile for Black's Nook Pond to study the effects of temperature on aquatic life. In the field, they collected data on the air temperature, the surface water temperature at different locations (e.g., in the middle, along the shore in the sun and in the shade), and the pond's temperature at various depths. In class, they collaboratively constructed a story that made sense of their data. But the path was a tortuous one, as the students first proposed theories to account for a portion of the collected data, then confronted additional data that conflicted with their initial theories, and finally proposed a new theory and an experiment to evaluate it.

For the temperature study, one student, Martine, collected data on the air and surface water temperature of the pond. Two other students, Sofia and Roudy, collected data on the pond's temperature at different depths around the pond. Martine and Roudy are Haitian; Sofia is Ethiopian. Martine and Roudy talked and wrote at times in Haitian Creole and at times in English; Sofia, being the only speaker of Amharic in the class, communicated solely in English.

To explore the students' scientific sense-making, we turn first to a videotaped interview that Sofia gave during the Black's Nook field study. At the time of the study, Sofia was 18-years old and had been speaking English for less than six months. Her native language, as we have noted, is Amharic. She was in a unique position in the classroom in that she was the only speaker of Amharic; most of the other students in the class had the advantage of sharing a language with other students and with at least one of the teachers. Sofia was therefore forced to do all her interacting -- her questioning, elaborating, writing, and the like -- in English, without the benefit of native language support.

In the interview, Sofia was simply asked to describe what she did for her temperature investigation. The transcript of her interview is given in Table 2. "R" is a researcher who conducted the interview; "S" is Sofia. During the interview, Sofia held a weighted thermometer that she made to take the measurements. It is a thermometer tied to a rope which is, in turn, tied to a large rock. The interview was conducted in English.

----- Insert Table 2 about here -----

It is clear from the interview that Sofia is struggling to realize a discourse form that is appropriate to the interviewer's question, a form that is beyond her current level of expertise in a language in which she not yet comfortable. She reports the temperatures that she and her partner, Roudy, found at different depths and at different places in the pond. She experiences some difficulty in coordinating expression of the depths and the temperatures, as is reflected in her "false start" in lines 9-10. However, because she is monitoring her report, she catches her mistake and corrects herself. ("In the first one, 5 feet and 2 inch, in the middle, I mean, tch...In the first one, 5 feet 2 inch and the temperature 19 degrees")

Her interview is marked by an almost telegraphic style which reveals the difficulty of the task she is attempting. Organizing and coordinating the expression of several pieces of numeric information in English is hard for Sofia and its complexity is reflected in her talk. She uses phrases rather than sentences to express herself and includes no information other than the temperature and depth numbers. Even her attempt to differentiate one measurement from another is uninformative for the uninitiated listener (e.g., "the first one, ...; the middle one, ...; the last one, ...;"). Nothing in what she says tells us that these temperatures were taken at different physical locations in the pond in addition to different depths. In effect, she is relying heavily on the physical context of the situation and her awareness that the interviewer knew what she had done to make her story coherent.

Interestingly, however, there is evidence to suggest even in this brief transcript that Sofia is beginning to develop a sense of what constitutes an adequate account of scientific activity. Although not specifically asked to describe her findings ("... just tell me what you did"), she struggles to share them with the interviewer. This suggests that she has developed a model of scientific activity that includes an understanding of the importance of data in scientific inquiry.

While the content of Sofia's interview is spare, it is not atypical of the kinds of talk that are generated by students new to the culture of scientific practice. For example, studies (Michaels & Bruce, 1989; Warren et al., 1989) have shown that, when asked individually to explain a phenomenon, some students offer a descriptive narrative of events rather than a causal

explanation, much as Sofia did. However, when knowledge is socially or collaboratively produced, it sometimes proves more robust than when it is produced by a lone individual. This is particularly true in the case of language minority students for whom the purely linguistic demands of expressing complex ideas can often mask their understanding. The next example illustrates the power of collaborative sense-making in science.

In class, the students reported their data. The transcript of their discussion is found in Table 3. In the discussion, Martine and Roudy reported their temperature readings from various depths and different locations around the pond. As the results were reported, they were recorded on the board. At the point where we join the transcript (Table 3), the group has established that the air temperature was 20 degrees Celsius. The class is led by a tutor (T) who assisted the classroom teachers (T2 and T3). (C) indicates that the text immediately following was spoken in Haitian Creole; (E) indicates English, and (S) indicates Spanish.

----- Insert Table 3 about here -----

In this transcript, we see that the students have uncovered a real and unexpected problem as they examine their data, namely, the apparent contradiction between their theory that the sun doesn't warm deeper waters and their data, showing that the air and deep water temperatures are virtually the same. As they try to understand the meaning of their data, they mobilize various discourse resources, building explanations, theories, conjectures, and evaluating evidence.

The manner in which they produced and then reported their data was a social process. Data collection was <u>distributed</u>, with different students, or groups of students, responsible for collecting data from different parts of the pond and then reporting their findings. Because data collection was distributed, the students had to share and communicate their findings with one another in order to construct a temperature profile. Thus, Martine contributed her data about the air and surface water temperatures, followed by Roudy who reported the data that he and Sofia, an Ethiopian student, collected on the water temperature at different depths.

But constructing a temperature profile is not a simple matter of data collection. There must be some theory that explains the pattern in the data. As the transcript shows, the process of understanding the data was also a

collaborative process that depended critically on the sharing of distributed knowledge. The clearest example of this comes in Lines 35-36 when Josefina, a young woman from El Salvador, first realized the discrepancy between the theory just elaborated to explain the difference between the air and water temperature (Lines 15-25) and the temperature reading taken five feet down in the pond, as reported by Roudy (Lines 27-33). Her remarks reveal that she had synthesized her fellow students' explanations and data reports and then analyzed their implications. Her "Wait a minute..." and the talk that follows it in Lines 35-36 is a particularly striking example of what Barnes (1976) has termed exploratory discourse, that is, of ideas being thought through even as they are being expressed. Josefina's conjecture was being formulated at the same time that it was being expressed. It is a type of discourse characteristic of discussions of ideas in contrast to discourse that is characteristic of lessons about answers of the kind most often found in school science (cf. Mehan, 1979).

The students' also began to explore different theories. Under the tutor's guidance, they began to build theories to explain the data (e.g., why the air was warmer than the water or not, as the case may be). Indeed, several theories were put forward, not all of which are included in the section of the transcript under discussion. One was that the air cools the water. Another was that the sun doesn't warm up the water as fast as the air. The most popular theory was that the sun doesn't reach the bottom of the water. That this theory should prevail over the others (especially the one stating that the sun warms up the air faster than the water) is interesting because in fact, while valid, it fails to account for the data it is intended to explain (namely, the discrepancy between the surface temperature and the air temperature). It may be one of those science "facts" the students picked up in another context or perhaps a phenomenon they have observed or experienced in other contexts.

Nevertheless, this theory, once stated, became pivotal to the discussion. The tutor, knowing that Roudy and Sofia had taken the temperature at the bottom of the pond, asked them to report their results. Their data proved discrepant with the class' theory: the water five feet down was warmer than the surface and nearly as warm as the air. This "monkey wrench," as Duckworth (1986) calls evidence or ideas that raise a question about what a learner has said so that the learner reflects more deeply on his own understanding, proved to be the catalyst for Josefina's additional analysis and reflection. Her reflections lead her to propose a more nuanced theory relating

the changes in the water temperature to the time of day. With scaffolding from the tutor, Josefina then began to design an experiment to test her theory. Thus, in this one classroom episode, the students collaboratively talked science, experiencing for perhaps the first time how data, theory, and experimentation interact to deepen scientific understanding.

Importantly, what emerges from this transcript is an altogether different interactional pattern between teachers and students than what typically takes place in science classrooms, let alone bilingual classrooms. To be sure, the tutor continued to orchestrate the interactions, but in a way that created opportunities for discussion, exploration of data and their meaning, and questioning of ideas. She created a context for collaborative discourse; each of her questions and each of the students' data reports and ideas contributed to a sense-making process. The point was to understand the meaning of the data they had collected. The effect was that the students actively participated in the discussion, constructing an understanding of the data they themselves had produced rather than rehearsing knowledge others had produced. It seems that the other teachers recognized this as well, expressing both their sense of engagement and discovery as the meaning of the data began to emerge from the class' discussion (Lines 21-24, 42, 45).

Turning now to the students' writing, we examine two examples, one by Sofia who did not actively participate in the classroom discussion and the other by Martine. As these examples make clear, writing science is also a form of storytelling in Medawar's sense. Moreover, it is one that presents many difficulties, requiring the writer to coordinate several discourse forms (e.g., narrative, explanatory and reportorial forms), to contextualize her discourse in terms of others (e.g., prior discussions, field work), in short, to find a voice through which she can express her own understandings and intentions.

In the classrom discussion, Sofia deferred to Roudy in reporting their data and did not contribute to the ensuing sense-making process. We should not interpret Sofia's silence as inactivity or non-participation, however. As Inagaki & Hatano (1983) have suggested, students can be highly engaged in an ongoing discussion regardless of whether or not they voice their thoughts aloud. What matters at least in part is the nature of the discussion itself. Students become engaged, even if only tacitly, to the extent that other students actively debate significant ideas. Sofia may also have been motivated to attend to the discussion because she had actively participated in

collecting the data.

Sofia's sense-making is reflected in a report she wrote on the temperature study. Through her report we are able to see that, although silent during the class discussion, Sofia was actively integrating and reflecting on what her fellow students were saying. Her report, reproduced in Table 4, combines both narrative and explanatory voices. As the report demonstrates, Sofia's view of her data was clearly shaped by the class discussion.

---- Insert Table 4 about here ----

Sofia begins her report in the voice with which she is most comfortable: the narrative or "I". Her report contains the essentials of a good narrative. She tells who, what, when, where and how her investigation occurred. Her piece is almost entirely composed of action statements (e.g., I put the thermometer in different parts of the water. I got there in the boat.) In fact, twelve of her fifteen sentences are of the "I did ___" construction. Interestingly, this construction is commonly practiced in English as a Second Language instruction. In this context, Sofia's use of the active, narrative voice clearly supports her scientific thinking and writing, and allows her to communicate what she did effectively. Through it, she paints a fairly detailed picture of her scientific method: we learn what she did, how she did it, what equipment she used, and so forth.

In her report, unlike her interview, Sofia also begins to organize her discourse at another level, that of explanation. At the end of her report, we see her struggling to break out of the narrative form with which she is comfortable and organize an explanation. But it is one that is still bound to the context in which it was first articulated, the class discussion. Sofia tries to explain Josefina's hypothesized reason for the discrepancy in the temperature data -- that Martine's surface temperatures were colder than the temperatures that she and Roudy found at deeper levels of the pond. She means to say that, as Josefina conjectured, Martine's temperatures were colder than theirs because hers were taken earlier and that by the time she and Roudy took theirs, the sun had warmed the water. But the task she has assumed is extraordinarily complex as she tries to explain discrepant results, other people's thinking about those results, and her own thinking about their thinking.

In a separate report, Martine, too, orchestrates different discourse forms in writing science. In many ways, her report of the temperature study is an interesting contrast to Sofia's (see Table 5). It was composed in Creole and then, as literally as possible, translated into English.

---- Insert Table 5 about here -----

Martine's report is noteworthy for its coordination of different ways of writing science, a kind of "heteroglot" discourse through which she attempts to reconstruct the class' discussion (Bakhtin, 1981; Cazden, 1989). Opening with the list of the temperature data that the tutor wrote on the board as the students reported their results, it continues with an "objective" explanation of each temperature reading, and then, switching into a narrative voice, it "tells the story" of Josefina's insight.

What emerges from Martine's report, and from the other examples we have been examining, is a sense of the complexities involved in her, or any student's, attempt to appropriate language for their own expressive purposes (which, as in this case, may be inextricably tied to the purposes of others such as one's teachers). In the process of trying to reconstruct her own and the class' theorizing, Martine makes use of several different discourses, including official classroom discourse represented in the list of temperature readings copied from the blackboard, and different forms of causal reasoning expressed in the first- and third-person.

For example, somewhere in her schooling (including the classroom temperature discussion in which the students' reasons for the discrepant data were emphasized), Martine has been made aware of a discourse of explanation, largely objective and impersonal, that is appropriate to school writing tasks and possibly also to scientific discourse. But it is one she has overgeneralized, as is demonstrated by the first two lines of her report. In Lines 1-2, for instance, the explanatory form she uses, "The air temperature was 20 C because the temperature was warm and I was in the sun," is confusing. It is as if she were saying, "I know the air temperature was warm because I was there and I felt it," a form of causal reasoning based on personal experience or evidence (Michaels & Bruce, 1989; Shiffrin, 1987). But the purpose for including this "explanation" is not really to explain so much as to establish the difference between the air and water temperature around which the classroom discussion revolved. Here Martine is trying, albeit not very effectively, to cope with the problem of contextualizing her discourse with

reference to an earlier discourse, that of the classroom discussion. (This is similar to the problem Sofia confronted in her interview but which she resolved by assuming knowledge of the immediate, physically present context of her temperature study.) Martine then goes on to explain the other temperature readings with a theory that relies partly on observable evidence (e.g., the trees shading the water from the sun) and partly on ideas -- actually mechanisms -- she proposes to explain the evidence (e.g., that the sun heats the air more than the water, that the deeper the water the cooler it will be because "the sun has more water to heat," and that the wind cools the water). Indeed, Martine marks these two aspects of her explanatory framework as different, when in Lines 6-8 she writes, "The water on the side under the trees was cool *too* because the sun couldn't shine on the water."

Martine's lack of control over the scientific sounding, explanatory discourse form stands in marked contrast to the fluency of the end of her report, Lines 8-11, when she invokes Josefina's reasoning to explain data she could not reconcile with her own theory. In these lines, she writes in the first person to explain that she does not know why the water five feet down was nearly as warm as the air temperature (again, the comparison is left implicit, indexed only by her inclusion of the 19°C reading). Referring to her theory, she writes, "I thought it would be cooled (sic)." She then invokes Josefina's reasoning as a possible explanation for the discrepant data, marking it as hypothetical ("Josefina thought maybe..."), subject to verification.

This example, along with Sofia's report, demonstrates how forcefully the intellectual community to which one belongs helps shape one's sense-making (Lampert, 1988; Schoenfeld, in press). As a group, the students theorized in the context of data they themselves had produced. In the process, they began to construct a story to explain their data. One student, Josefina, helped the other students see their data in a new light, possibly uncovering a flaw in their data collection procedure. Having uncovered data that is discrepant with their emerging theory, she then proceeded to design an experiment to test her conjecture, echoing the process of conjecture and criticism that Medawar argues is characteristic of scientific inquiry. The force of Josefina's perspective is reflected in both Martine's and Sofia's reports.

In the examples we also see some interesting patterns of discourse organization. The students used both narrative and explanatory discourse forms. And, in both Sofia and Martine's reports, the narrative voice

functioned in several ways: to recount methodology, to provide evidence from one's personal experience in explaining some finding, and, most interestingly, to signal agreement with or acknowledgement of another student's explanation, and to confess one's puzzlement over data that proved contradictory with one's theory. These latter two cases are of most interest to us here because they show narrative playing a mediating role in scientific reasoning as the students try to understand the meaning of the data they have collected in the context of one or another theory. Gaining control over this dialogue between data and theory (or theory and data, since the dialogue goes both ways) is at the heart of what it means to be scientifically literate.

Conclusion

The foregoing examples of student talk and writing all demonstrate the complexities involved in scientific sense-making and the necessary connection between such sense-making and the community of practice in which it takes place. In every case we examined, the dilemmas and issues the students met (e.g. how to explain data, how to reconcile data and theory, how to draw out the implications of findings) grew directly out of their own scientific activity. This activity encompassed many elements of authentic scientific inquiry: question posing, conjecturing, theorizing, data collection and analysis, and experimentation. In this context, the purposes of classroom talk and writing shifted from ordinary practice, away from transmitting the teacher's meaning system (or the text's) and evaluating the students' mastery of it to students' actually constructing the meaning of their data and evaluating their own sense-making. They became knowledge producers and active sense-makers, not mere assimilators of knowledge produced or recounted by authoritative others. In fact, through their questions and explorations, the students sought knowledge that neither they nor the teachers already possessed.

In this new culture of scientific practice, knowledge was socially constructed. Just as scientific activity was distributed, so was the knowledge produced by this activity. Sense-making, then, came to depend upon a community process of data sharing, analysis, and evaluation in terms of alternative theories, analogous to the kind of sense-making process in which scientists, and most other professionals, engage in their research. In the temperature study, for example, the students showed how they could help one another make sense of data, as they theorized in the context of data they

had produced. Martine's report, in which she incorporates Josefina's theory to explain data she could not reconcile on her own, stands as another example of how understanding was socially mediated.

As each of the examples shows, the problem of learning to make sense in science as much as in other disciplines is in many respects a problem in finding a voice (i.e., controlling a discourse) through which one can express one's own intentions, experiences and values, a problem that Cazden (1989) has explored in a recent paper relating the work of the Soviet theorist Bakhtin (1981) on language to the developing writer's struggle. As Cazden explains, the struggle is not just to learn new ways of writing (or thinking or talking) but ways of expropriating particular discourses and the values of the contexts with which they are associated to one's own purposes. Scientific discourse, in particular, is a discourse of theorizing which draws upon narrative, explanatory, conjectural and still other discourse modes. In the examples analyzed in this paper, we see that for Martine, Sofia, Rosealta and Josefina, learning to tell good stories in science is not simply a matter of mastering a particular explanatory or narrative form, as is typically emphasized in English as a Second Language instruction. Rather, learning to think, talk and write scientifically is a matter of understanding the approach to knowledge and reasoning, and the values and assumptions that science embodies and of finding a way to accommodate one's purposes and values alongside those of the scientific and school cultures.

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Table 1

Rosealta and Martine's Questions

I went to know How come bacteria come in the water?

How much chlorinatin do they put in the water to clearn it?

How come they clearn the water but it still has bacteria in it?

I went to know how often they clean the water?

What percent chemical products is in the water?

Table 2

Sofia's Interview

R: Ok Sofia, I'm ready. Hold it up [the thermometer] and just tell me what you did with it.

S: Do you want [me to] tell you what ...?

R: Yup.

S: This is for inside the pond [pointing to the thermometer]. I took the temperature so many feet, so many inch - in the middle, in the beginning, and the last one.

R: How many measurements did you take?
[S holds up the weighted thermometer.]

S: In the first one, 5 feet and 2 inch; in the middle, I mean, tch... In the first one, 5 feet 2 inch and the temperature 19 degree. In the middle, 6 feet, 6 feet and 19 degree. And the last one, 6 feet 1 inch and 19 degree.

R: Great.

Table 3

Class Temperature Discussion

1 T: (E) Okay, so the air temperature was 20. Okay, Martine, what other results
2 did you find?

3 Martine: From the side, from the side, from the side (...) in the water, it was 18.

4 T: Okay.

5 Martine: (C) The surface of the water was 15.

6 T: The surface where?

7 Martine: In the water, in the middle (...) And near, (...) near the side of the
8 water under the trees (...), it was 15.

9 T: (E) Okay. These were the results Martine found. Can anybody explain
10 why they think, what the changes were about? Why weren't they the same?

11 Martine: (C) Why above the water was, where when I first came the air was 20
12 was because it was a bit warm out and also the air (...).

13 T: (E) Okay, what Martine is saying, she's saying that when we came to the
14 pond it was pretty warm outside and that's why she thinks it was 20. What do
15 people think? Why would the water be, I don't understand why the water
16 would be different from the air.
(...)
17 Martine: (C) Because under the water, the sun doesn't hit the bottom of the
18 water.

19 Mario: (E) The sun wasn't going the bottom of the water.

20 Lorenzo: (S) The water on top is hot, because the sun hits it, but the water in the
21 bottom is (...).

21 T2: (E) Alright! Lorenzo got, just got that. See if you try to get it! The
22 temperature, can I translate for Lorenzo? He told me in Spanish. The water
23 on top of the pond is warmer than deeper down because the sun heats up the
24 water on the top.

25 T: (E) Okay, that's just what Mario was saying. Okay, great. Is that true? Did
anybody measure the water down below?

26 Roudy: We did.

27 T: Who did that? Roudy? Do you remember? What were your results?

28 Roudy: (C) 19 degrees.

29 T: (E) Okay, Roudy says it was 19. Everybody listen to this. Roudy and
30 Sofia took the temperature down under the water. Roudy, (C) how many feet
31 down?

32 Roudy: (C) Five.

33 T: (E) Okay. (Writing on board.) "Under the water five feet down it was
34 19 degrees." Okay, listen. Lorenzo, can you explain this?
(...)
35 Josefina: Wait a minute. The air was 20, the air was 20, and the the the the
36 water was 19? Maybe it later on it was (...).

37 T: Later on? Can you explain a little more?

38 Josefina: (...)

39 T: Hey listen to this. That's a great idea!
(...)
40 T: Listen, what Josefina said was, look, Martine took the 20 degrees when she
41 first came, right?

42 T3: Uh huh.

43 T: And then Roudy and Sofia did the temperature at about 12 o'clock or later,
44 right?

45 T2: Ohhh!

46 T: And she's saying maybe the sun had time to warm it up.
...
47 T: If we go this Wednesday, what should we do to check? What would you
48 do, Josefina?

49 Josefina: Measure it (...) at two times, in the morning and at 12
50 o'clock.

51 T3: Once at this hour and once at this time? When you get there?

52 Josefina: Uh huh. (...) And at 12 o'clock, 12 o'clock. Most of the
53 time at 12 o'clock the sun is hotter.

54 T: Okay. If you did it (...). But isn't that what we did? She did it in the
55 morning and then they did at 12 o'clock, right? So what do you want to do
56 differently? What's different about what you are saying? What ? Because
57 Martine, she did it in the morning and then Roudy did it in the afternoon. How 58
do you want to change it?

59 Josefina: He did it in the afternoon, I mean, you know, like the morning,
60 sunshine. Then at 12 o'clock is more hotter.

61 Tutor: Okay, so what do you want to do in the morning?

62 Josefina: Measure the temperature.

63 T: Where? Which temperature?

64 Josefina: In the water. Outside and in the water.

65 T3: So you want to do in the water, in the air and the water. We're talking
66 about both, both times? Both of them at both times? Both of them in the
67 morning and both of them at 12?

68 Josefina: Yeah! (...) Two different sets!

69 T: Great idea. Maybe the air outside the water.

70 T3: You're going to do that, Josefina? Okay, Josefina gonna handle that.

71 T2 (to Lorenzo): (S) In the morning and the afternoon. Do you want to help
72 her?

73 Lorenzo: (S) Mmhmm, but again it would be around 4 that we return?

74 T2: (S) Yes, we don't leave until around 4.

75 Lorenzo: (S) I'll stay, it doesn't matter, to take the temperature too.

76 T2: (E) Lorenzo says he'll stay until 4 o'clock and take another temperature. I
77 told him he could if he wanted to.

78 Tutor: Okay, that's a good experiment.

Table 4
Sofia's Report

Last Wednesday, I was doing the temperature. I put the thermometer in different parts of the water. I tied a rope around a rock and the thermometer together. The first time was at 5' 2" the temperataure was (19° C) Then second I meashired the temperatre 6' 1" and it was (19° C)

I did this in the middle of the pond. I got there in the boat. I was with Roudy and Mr. D. then I measured the temperature the lat time. I ded This on the other side of the pond. the temperataure was (19° C) at 6; 1" then I seur back across the pond when I had started. I wrote every thing down in my notabook. I aegree with Josefina in the moening the shine on stringly, on thats why the water Martine measured it cold (15° C) . in the afternoon the sun is strong.

Table 5

Martine's Temperature Report

The air temperature was 20 degrees C.
The water near the side was 18 C.
Under the surface of the water in the middle
of the pond was 15 C.
On the side of the water under the trees, it was 15 C.
Under the water 5 ft down the temperature was 19 C.

The air temperature was 20 C because the temperataure was warm and I was in the sun.
The water was cooler than the air because the sun was shining more on the air than on the water the wind blew on the water and cooled it. Under the surface of the water in the middle of the pond was cooler because the middle was deeper than on the side so the sun had more water to heat. The water on the side under the trees was cool too because the sun couldn't shine on the water. I don't know why the water was 19 c. 5 ft down I thought it would be cooled. Josefina thought maybe it was because I took the temperature in the morning and they took the temperature in the after noon when it was warmer.

END

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